

1 WHAT IS CLAIMED IS:

2 1. A system for controlling particle accelerators, comprising:  
3 a distributed control system that further comprises:  
4 a computing device operable to execute a first software  
5 tool that identifies variable inputs and controlled  
6 variables associated with the particle accelerator, wherein  
7 at least one variable input is a manipulated variable  
8 input, and wherein said first software tool is further  
9 operable to determine relationships between said variable  
10 inputs and said controlled variables; and  
11 at least one input/output controller operable to monitor  
12 said variable inputs and tune said manipulated variable to  
13 achieve a desired controlled variable value.

14 2. The system for controlling particle accelerators of Claim  
15 1, wherein said relationships between said variable input  
16 parameters and said controlled variables comprises a first  
17 principle models wherein said first principle model is  
18 dependent on said variable inputs.

19 3. The system for controlling particle accelerators of Claim  
20 1, further comprising neural networks utilized to identify  
21 said variable inputs.

22 4. The system for controlling within particle accelerators of  
23 Claim 1, wherein said step of determining relationships

1       between said variable inputs and said controlled variables  
2       utilizes a combination of physical models and empirical  
3       methods.

4       5. The system for controlling particle accelerators of Claim  
5       4, wherein said physical models and empirical methods are  
6       combined in series.

7       6. The system for controlling particle accelerators of Claim  
8       4, wherein said physical models and empirical methods are  
9       combined in parallel.

10      7. The system for controlling particle accelerators of Claim  
11       4, wherein said physical model varies over an operating  
12       range..

13      8. The system for controlling particle accelerators of Claim  
14       5, wherein said physical model is a function of said  
15       variable inputs.

16      9. The system for controlling particle accelerators of  
17       claim 7, wherein said physical model comprises first  
18       principle parameters which vary with said variable inputs,  
19       wherein empirical methods comprise a neural network used to  
20       identify first principle parameters values associated with  
21       said variable inputs, and wherein said neural network

1       updates said first principle parameters with values  
2       associated with said variable inputs.

3    10. The system for controlling particle accelerators of Claim  
4       9, wherein said neural network is trained.

5    11. The system for controlling particle accelerators of Claim  
6       9, wherein said neural network is trained according to at  
7       least one method selected from the group consisting of:  
8       gradient methods, back propagation, gradient-based  
9       nonlinear programming methods, sequential quadratic  
10       programming, generalized reduced gradient methods, and non-  
11       gradient methods.

12   12. The system for controlling particle accelerators of Claim  
13       11, wherein gradient methods require gradients of an error  
14       with respect to a weight and bias obtained by numerical  
15       derivatives.

16   13. The system for controlling particle accelerators of Claim  
17       11, wherein gradient methods require gradients of an error  
18       with respect to a weight and bias obtained by analytical  
19       derivatives.

20   14. The system for controlling particle accelerators of Claim  
21       10, wherein said controlled variablecomprises a magnetic  
22       field strength, shape, location and/or orientation and said

1       controlled variable comprises particle positions within  
2       said particle accelerator.

3   15. The system for controlling nonlinear control problems  
4       within particle accelerators of Claim 14, wherein said step  
5       of tuning said manipulated variable comprises adjusting a  
6       connector magnet and/or quadrupole magnet.

7   16. A dynamic controller for controlling the operation of a  
8       particle accelerator by predicting a change in the dynamic  
9       variable input values to the process to effect a change in  
10      the output of the particle accelerator from a current  
11      output value at a first time to a different and desired  
12      output value at a second time to achieve more efficient  
13      collisions between particles, comprising:  
14       a dynamic predictive model for receiving the current  
15      variable input value, wherein said dynamic predictive model  
16      changes dependent upon said input value, and the desired  
17      output value, and wherein said dynamic predictive model  
18      produces a plurality of desired controlled variable values  
19      at different time positions between the first time and the  
20      second time to define a dynamic operation path of the  
21      particle accelerator between the current output value and  
22      the desired output value at the second time; and

1       an optimizer for optimizing the operation of the dynamic  
2       controller over a plurality of the different time positions  
3       in accordance with a predetermined optimization method that  
4       optimizes the objectives of the dynamic controller to  
5       achieve a desired path, such that the objectives of the  
6       dynamic predictive model vary as a function of time.

7 17. The dynamic controller of claim 16, wherein said dynamic  
8       predictive model comprises:

9       a dynamic forward model operable to receive variable input  
10      values at each of said time positions and map said variable  
11      input values to components of said dynamic predictive model  
12      associated with said received variable input values in  
13      order to provide a predicted dynamic output value;  
14      an error generator for comparing the predicted dynamic  
15      output value to the desired output value and generating a  
16      primary error value as the difference for each of said time  
17      positions;

18      an error minimization device for determining a change in  
19      the variable input value to minimize the primary error  
20      value output by said error generator;

21      a summation device for summing said determined variable  
22      input change value with an original variable input value,  
23      which original variable input value comprises the variable  
24      input value before the determined change therein, for a

1       plurality of time position to provide a future variable  
2       input value as a summed variable input value; and  
3       a controller for controlling the operation of said error  
4       minimization device to operate under control of said  
5       optimizer to minimize said primary error value in  
6       accordance with said optimization method.

7       18. A method for controlling particle accelerators, comprising  
8       the steps of:  
9       identifying variable inputs and controlled variables  
10      associated with the particle accelerator, wherein at least  
11      one variable input parameter is a manipulated variable;  
12      determining relationships between said variable inputs and  
13      said controlled variables wherein said relationship  
14      comprises models, and wherein parameters within said model  
15      are dependent on said variable inputs; and  
16      tuning said manipulated variable to achieve a desired  
17      controlled variable value.

18       19. The method of Claim 18, wherein said step of  
19       identifying parameters utilizes neural networks to identify  
20       said parameters.

21       20. The method of Claim 18, wherein said step of identifying  
22       parameters utilizes neural networks that identify said  
23       parameters when an operating region changes.

- 1 21. The method of Claim 18, wherein said step of identifying
- 2 parameters utilizes neural networks that identify said
- 3 parameters.
- 4 22. The method of Claim 18, wherein said step of determining
- 5 relationships between said variable inputs and said
- 6 controlled variables utilizes a combination of physical
- 7 models and empirical methods.
- 8 23. The method of Claim 22, wherein said physical models and
- 9 empirical methods are combined in series.
- 10 24. The method of Claim 22, wherein said physical models and
- 11 empirical methods are combined in parallel.
- 12 25. The method of Claim 22, wherein said physical model varies
- 13 over an operating range.
- 14 26. The method of Claim 25, wherein said physical model is a
- 15 function of said variable inputs.
- 16 27. The method of Claim 26, wherein said physical model
- 17 comprises first principle parameters which vary with said
- 18 variable inputs, wherein empirical methods comprise a
- 19 neural network used to identify first principle parameter
- 20 values associated with said variable inputs, and wherein

1        said neural network updates said first principle parameters  
2        with values associated with said variable inputs.

3    28. The method of Claim 27, wherein said neural network is  
4        trained.

5    29. The method of Claim 28, wherein said neural network is  
6        trained according to at least one method selected from the  
7        group consisting of gradient methods, back propagation,  
8        gradient-based nonlinear programming (NLP) methods,  
9        sequential quadratic programming, generalized reduced  
10        gradient methods, and non-gradient methods.

11    30. The method of Claim 29, wherein gradient methods require  
12        gradients of an error with respect to a weight and bias  
13        obtained by either numerical derivatives or analytical  
14        derivatives.

15    31. The method of Claim 18, wherein said manipulated variable  
16        comprises a magnetic field strength, shape, location and/or  
17        orientation and said controlled variable comprises particle  
18        positions within said particle accelerator.

19    32. The method of Claim 31, wherein said step of tuning said  
20        manipulated variable comprises adjusting a connector  
21        magnet.

- 1 33. The method of Claim 31, wherein said step of tuning said
- 2 manipulated variable comprises adjusting and quadrapole
- 3 magnet.
  
- 4 34. The method of Claim 31, wherein said step of tuning said
- 5 manipulated variable comprises adjusting a connector magnet
- 6 and quadrapole magnet.